Precision Agric (2012) 13:141–147
DOI 10.1007/s11119-011-9241-6

Evaluation of an auto-guidance system operating on a sugar cane harvester

Fábio Henrique Rojo Baio

Published online: 9 August 2011

Abstract Precision farming tools such as auto-guidance systems assembled on tractors and/or sugar cane harvester machines are being applied to decrease the costs involved with ethanol production. The purpose of this study was to evaluate the accuracy, the cane loss and the operational field efficiency achieved by an auto-guidance system used to guide a sugar cane harvester over the field when compared to a manually-guided machine. The field test was conducted with two treatments: auto-guidance versus manual guidance; and day versus night. Each treatment was replicated four times. Each position recorded represented a single sample, which was used to calculate the error between the planned and actual paths. It was concluded that the use of an auto-guidance system operating on a sugar cane harvester during the day and night periods increased the field pass-to-pass accuracy relative to the planned row track, but it is essential that the crop was planted using the system. The use of the auto-guidance system did not significantly decrease the sugar cane loss, once the crop was well cultivated. More long-term research needs to be done related to this issue. The operational field efficiency of the cane harvester was the same for both auto-guidance and manual steering systems.

Keywords Auto-guidance · GPS · Sugar cane · Operational field efficiency · Harvester

Introduction

The adoption of mechanized harvest techniques has caused an increase in harvest losses. In addition, mechanization has increased the vegetative and mineral impurities that are taken to the mill together with the harvested cane. Recently, precision farming techniques have been applied to decrease the input costs involved with ethanol production by decreased use of agrochemicals and other agricultural inputs, contributing to a better energy balance for ethanol production from sugarcane. Silva et al. (2011) showed that 39% of the sugar cane mills in Brazil adopted auto-guidance technology, 31% adopted geo-referenced soil

F. H. R. Baio (✉)
UFMS, P.O. Box 112, Chapadao do Sul, MS 79560-000, Brazil
e-mail: fabiobaio@ufms.br

sampling and 29% adopted variable rate fertilizer and lime application. The use of machines steered by GPS (Global Positioning System) with auto-guidance can improve the mechanized system. According to Stombaugh et al. (2008), the most commonly used satellite-based radio-navigation system is GPS, which is maintained by the United States Department of Defense; however, there are several other similar systems that are currently in use or development. The term GNSS (Global Navigation Satellite System) has been adopted to describe this family of satellite-based positioning technology. According to Stabile and Balastreire (2006), the high cost of a GNSS system has delayed the use of precision farming techniques in Brazil. The market offers several GNSS receiver models that can be used in steering applications and most of them use Real Time Kinematic (RTK) differential correction, which can provide 25 mm of pass-to-pass accuracy (Trimble, 2011). An obvious benefit of the use of these systems is the pass-to-pass error reduction, when compared to a manual steering method. According to Baio (2005), GPS cannot be used for only a single operation, such as spraying, but needs to be used as much as possible within an agricultural year, in order to spread its acquisition cost.

Balastreire and Baio (2002) showed that Differential GPS (DGPS) can be replaced by an algorithm error correction, such as the e-Dif algorithm (Hemisphere 2011), which corrects the horizontal positioning error without any broadcast differential signal. This type of free correction of the GPS error is well accepted in the South American market since WAAS (Wide Area Augmentation System) and EGNOS (European Geostationary Navigation Overlay Service) differential corrections are not available, or are not accurate for this region. Since this type of correction works in the autonomous GPS mode only, it cannot reach RTK-level accuracy. Baio (2007) stated that some agricultural operations like mechanized sugar cane planting or harvesting require 5 cm accuracy and the common DGPS cannot offer. The author also comments that the sugar cane agricultural segment in Brazil is increasing investment in auto-guidance systems. Shockley and Dillon (2008) reported that auto-guidance decreases overlapped application, increases operational speed, allows a higher accuracy at input application, and increases the available time to finish the operation. Batte and Ehsani (2006) showed that the cost reduction achieved by the use of this technology is substantial.

The purpose of this study was to evaluate the accuracy, the cane loss and the operational field efficiency achieved by an auto-guidance system used to guide a sugar cane harvester over the field when compared to a manually-guided machine.

Materials and methods

The field evaluation was made on the Campanelli Farm located at Sao Jose do Rio Preto city, Brazil (Latitude 22°35′52″S and Longitude 49°08′21″WG). This farm provides sugar cane for the Guarani Sugar Cane Mill. The field work was conducted during the first week of August, 2009. Solar activity, which could affect GNSS accuracy, was considered low during this time with 66 Solar Flux Units (SFU) at the F10.7 index (Brunini and Azpilicueta 2010). The F10.7 index is a measure of the solar radio flux per unit frequency at a wavelength of 10.7 cm. The slope topography of the field, with a clay soil type, was less than 5% and the 1.5 year-old cane was being harvested for its first cut. In the field where the test was performed, the average cane yield was 120 t ha^{-1}. The tractor used to plant the cane was equipped with an auto-guidance system. The driver had 6 months of experience level with the harvester.

A CASE model 7700 sugar cane harvester (CASE IH, Piracicaba, SP, Brazil) on tracks was used in this test. It was equipped with a Trimble AutoPilot auto-guidance system (Trimble Navigation Ltd., Sunnyvale, CA, USA), with an AgGPS 262 receiver, and AgGPS NavController II (Trimble Navigation Ltd., Sunnyvale, CA, USA). RTK correction was provided via radio link. All passes were recorded by the Trimble FMX monitor, which recorded the points with machine tilt error already corrected by the terrain compensation module. The GPS antenna was positioned at the top and the center of the machine's cab, assembled as from factory. The harvester top cutter was deactivated during tests because of the cane condition. The same autosteer equipment model was installed in three tractors that pulled the cane wagons during the tests. The tractors used the same reference tracks as the cane harvester.

A Trimble AgGPS RTK 450 (Trimble Navigation Ltd., Sunnyvale, CA, USA) was used as the base station. This base station was positioned over a geo-referenced point located 1200 m from the field. The maximum age of the RTK signal correction was set to 30 s.

The number of available GPS satellites was always greater than five during all tests and the dilution of precision was always less than four. Trimble AutoPilot was set to follow the reference tracks recorded on the Trimble FMX monitor. The swath width was set to 1.4 m, the same as the row spacing of the cane. The path generation method used on the guidance monitor was the identical curve method (Trimble 2011). The GPS logging interval and the look ahead guidance parameter were set to one second. The GPS elevation mask angle was set to 15°.

The field test was conducted with four replications at two major treatments: auto-guidance versus manual guidance and day versus night. Each position recorded represented a single sample which was used to calculate the error as compared with the planned pass. Each pair of treatments (manual and automatic steering) was conducted in adjacent rows. The replications were conducted in different sections of the same field. The statistical analysis was made with Sisvar 5.1 software (Ferreira 2008) calculating the Tukey test at 5% significance.

The methodology described by Balastreire (2007) was used to calculate the machine's field efficiency and its operational field capacity. The data collected were the total time, maneuver time, refueling stops, maintenance and sugar cane wagon waiting time. These times were collected with a digital chronometer. The speed of the cane harvester was kept at 3.7 km h^{-1}. This speed was chosen according to the sugar cane plant size and vigor.

The co-ordinates of the row passes recorded (sequenced points) were exported from the Trimble FMX monitor to the GIS (Geographical Information System) SSToolbox 3.8.0 (SST 2011), where the data were manipulated and the row pass maps were generated. The field co-ordinates were, then, exported to a spreadsheet, where they were converted to UTM (Universal Transverse Mercator) format, and the errors were calculated.

The methodology used to calculate the relative positioning accuracy was suggested by Stombaugh et al. (2008). They also distinguish between absolute and relative positioning accuracy. According to the authors, "absolute accuracy is the measurement regarding to a true reference position and relative accuracy is the measurement regarding to other navigation data records collected from the same receiver". As suggested by Stombaugh et al. (2008), the reference points were extracted from the poly-line representation of the reference track and projected into the localized co-ordinate system (Fig. 1). The reference track was constructed with a pair of a Trimble R3 L1 GPS, with the post-processed correction method, which can attain millimeter accuracy. The reference track was also used to plant the cane in the previous year with the same Trimble AutoPilot System, assembled on the tractor. Also as they suggested, "these points of the reference track were spaced

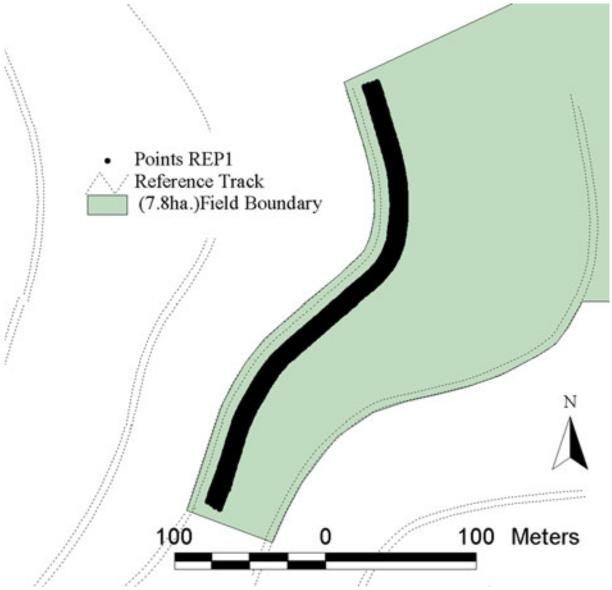

Fig. 1 Map illustrating the reference track related to the passes recorded during the first replication of the test

0.01 m apart along the track path and the off-track error was calculated for each data point by finding the minimum distance from the data point to any of the points on the track". The radius of the reference curves followed the contour curves on the field, with a minimum of 50 m. Figure 1 shows that the orientation of the reference tracks followed a direction trend from SW to NE. "Unless the data point was directly perpendicular to the closest reference point, the error would be slightly larger than the true perpendicular distance to the reference trajectory (Stombaugh et al. 2008)". This calculation routine was done with a spreadsheet macro.

During the manual steering test, all auto-guidance monitors and GPS displays were hidden from the driver, who was the same for all tests.

The sugar cane loss was calculated according to the methodology suggested by Benedini et al. (2011), where all parts of sugar cane left behind on the field by the harvester, besides sugar cane root, were collected in a sampled area and weighed.

Results and discussion

Table 1 shows the statistical Tukey test of the average error comparison between the treatments. It can be observed that the manually-guided system had a higher error (0.183 m) when compared to the auto-guidance system (0.039 m). According to John Deere (2011), "RTK accuracy levels are described on a static basis measured at the vehicle receiver 68% of the time" and can attain an accuracy of 25 mm, however, this accuracy was measured under static conditions. To perform the harvesting operation with the auto-guidance system, it is essential that the crop was planted with an auto-guidance system as well; otherwise, the harvester machine will follow the planned rows which do not match

Table 1 Tukey test of the average error comparison between the treatments, when the sugar cane harvester machine was guided by the manual and auto-guidance systems

Treatments	Period	Error (m)[a]
Auto-guidance	Day	0.052
Manual	Day	0.143
Auto-guidance	Night	0.026
Manual	Night	0.223
Auto-guidance—Total	Day and night	0.039 B
Manual—Total	Day and night	0.183 A

[a] Averages followed by the same letter on the column do not differ by the Tukey test at 5% significance. DMS (Minimal significance difference): 0.016

Table 2 Tukey test comparison between the averages of the treatments

Treatments	Sugar cane loss Average ($t\ ha^{-1}$)[a]
Auto-guidance	3.69 A
Manual	3.84 A

[a] Averages followed by the same letter on the column do not differ by the Tukey test at 5% significance. DMS: 4.67

Table 3 Operational machine field efficiency (%) comparison between manual and auto-guidance systems measured within the day and night periods

Treatments	Periods	Operational field efficiency (%)
Auto-guidance	Day	80.0
Manual	Day	79.4
Auto-guidance	Night	83.4
Manual	Night	86.0
Auto-guidance—Total	Day and night	81.7
Manual—Total	Day and night	82.7

the planted rows. According to Baio (2007), the irregularity of row spacing in sugar cane is the major cause of cane damage in the following year caused by the sugar cane harvester.

Table 2 shows the comparison between the sugar cane losses. According to the classification suggested by Benedini et al. (2011), the sugar cane loss was low. It was observed that the use of the auto-guidance system did not significantly decrease the sugar cane loss. More research needs to be done related to this issue. The auto-guidance can keep the harvester over the planned track, but the cutting height position is done by another electronic system which can exert much more influence on the cane losses and impurities than the steering system. Also, it is must be reported that by the time of the test, the cane was not lying on the ground. The cane loss can increase in this condition and the auto-guidance system might have some advantage.

The large advantage in using a steering system based on GNSS is the improvement in accuracy of the passes in between the row tracks, thereby avoiding the machine passing

over the planted row. This accuracy improvement results in an indirect financial advantage of enhanced cane yield over the years by the reduction of in-row soil compaction and root damage. More long-term research needs to be done related to this issue.

From the machine times collected in the field during day and night operations, it was possible to calculate the operational field efficiency of the mechanized systems (Table 3). The averages (about 80%) were very similar when comparing the guidance methods in the two light conditions. They were considered adequate for this kind of operation, as indicated by ASAE (2000). According to the mechanized cane harvest system used in Brazil, a cane wagon follows the harvester until it is filled with the cut cane. However, the harvester did the U-turns at the ends of the rows faster than the cane wagon and that affected the total operational field efficiency of the mechanized system, independent of the steering method.

Conclusions

The use of an auto-guidance system operating on a sugar cane harvester during the day and night periods increased the field pass-to-pass accuracy relative to the planned row track, but it is essential that the crop was planted using the system.

The use of the auto-guidance system did not significantly decrease the sugar cane loss, once the crop was well cultivated. More long-term research needs to be done related to this issue.

The operational field efficiency of the cane harvester was the same for both auto-guidance and manual steering systems.

Acknowledgment Special thanks to Campanelli Farm that provided all field test support, Santiago & Cintra and Guarani Sugar Cane Mill.

References

ASAE. (2000). *ASAE D497.4: Agricultural machinery management data. 47* (pp. 350–357). St. Joseph: ASAE.

Baio, F. H. R. (2005). Metodologia para ensaio de sistemas de direcionamento via satélite em percursos retos e curvos (Methodology for steering systems tests in straights and curves operations). Ph.D. Thesis—FCA/UNESP, p.100, Brazil: Botucatu.

Baio, F. H. R. (2007). Aplicação de AP no plantio (Application of PA in the planting). In T. C. C. Ripoli, M. L. C. Ripoli, D. V. Casagrandi, & B. Y. Ide (Eds.), *Plantio de cana-de-açúcar: estado da arte (Sugar cane planting: State of the art). 2* (pp. 92–101). Piracicaba: T.C.C. Ripoli.

Balastreire, L. A. (2007). Máquinas agrícolas (Agricultural machines). 3. Balastreire, L.A. (Ed.), p. 307. Piracicaba.

Balastreire, L. A., & Baio, F. H. R. (2002). Avaliação do desempenho de um GPS com algoritmo otimizado sem sinal de correção para a agricultura de precisão (Performance evaluation of a GPS with optimized algorithm without differential correction for precision agriculture). In: Balastreire, L. A. (Ed). Avanços na agricultura de precisão no Brasil no período de 1998–2001 (Advances in precision agriculture in Brazil from 1998–2001), pp. 285–288. Piracicaba.

Batte, M. T., & Ehsani, M. R. (2006). The economics of precision guidance with auto-boom control for farmer-owned agricultural sprayers. *Computers and Electronics in Agriculture, 53*(1), 28–44.

Benedini, M. S., Brod, F. P. R., & Perticarrari, J. G. (2011). Perdas de cana e impurezas vegetais e minerais na colheita mecanizada (Loss of sugarcane and vegetative and mineral impurities in mechanized harvesting). Retrieved May 5, 2011, from http://www.canaoeste.com.br/boletim2009_03.pdf.

Brunini, C., & Azpilicueta, F. (2010). GPS slant total electron content accuracy using the single layer model under different geomagnetic regions and ionospheric conditions. *Journal of Geodesy, 84*, 293–304. doi:10.1007/s00190-010-0367-5.

Ferreira, D. F. (2008). SISVAR: Um programa para análises e ensino de estatística (SISVAR: A software for analysis and teaching statistics). *Symposium, 6*(2), 36–41.

Hemisphere. (2011). e-Dif. Retrieved May 5, 2011, from http://www.canalgeomatics.com/product_details.php?product_id=149.

John Deere. (2011). Scalable accuracy. Retrieved May 5, 2011, from http://salesmanual.deere.com/sales/salesmanual/en_NA/ams/2011/feature/starfire_3000/accuracy_needs.html?sbu=ag&link=prodcat.

Shockley, J. M., & Dillon, C. R. (2008). Cost savings for multiple inputs with swath control and auto guidance technologies. In R. Khosla (Ed.), *Precision agriculture, Proceedings of the 9th international conference on precision agriculture*. Denver: Colorado State University (CD Publication).

Silva, C. B., Moraes, M. A. F. D., & Molin, J. P. (2011). Adoption and use of precision agriculture technologies in the sugarcane industry of São Paulo state, Brazil. *Precision Agriculture, 12*(1), 67–81.

SST. (2011). SSToolbox. Retrieved May 5, 2011, from http://www.sstsoftware.com/sstoolbox.htm.

Stabile, M. C. C., & Balastreire, L. A. (2006). Comparação de três receptores GPS para uso em agricultura de precisão (Comparison of three GPS receivers for precision agriculture uses). *Engenharia Agrícola, 26*(1), 215–223.

Stombaugh, T. S., Sama, M. P., Zandonadi, R. S., Shearer, S. A., & Koostra, B. K. (2008). Implications of standardized GNSS accuracy testing. In R. Khosla (Ed.), *Precision agriculture, Proceedings of the 9th international conference on precision agriculture*. Denver: Colorado State University (CD Publication).

Trimble. (2011). Guidance. Retrieved May 5, 2011, from http://www.trimble.com/agriculture/guidance.aspx.